Interaction of renewable & conventional energies – large-scale battery systems as a connecting link

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Kurzfassung
Zusammenspiel von erneuerbaren und konventionellen Energien – Großbatterie-Systeme als Bindeglied


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Introduction
Today’s electricity supply in Germany is based on the existence of large central power plants that ensure electricity supply and stability of the supply network. As a consequence of the nuclear phase-out adopted by the government and the progressive energy transition, 55 to 60 percent of the German gross electricity demand is to be covered by energy from renewable sources by 2035. The decreasing proportion of energy fed into the grid by conventional power plants and the increasing proportion of fluctuating infeed from renewable energy sources require a flexibilisation of power supply, especially in lower-level voltage systems. As photovoltaic systems and wind turbines are unable, due to their volatility and the uncertainty in generation forecasts, to provide the required system services at all times, the demand for alternative technologies for the provision of these services is increasing.

Main Part
Battery systems and the “Energiewende”
Already today, priority infed of electricity from renewables causes conventional power plants more and more often to be temporarily squeezed out of the market, whenever wholesale prices fall below the generating costs. During the resulting shutdown periods the conventional plants therefore cannot contribute to maintaining the system stability of the European interconnected grid. However, the transmission system operators (TSOs) are obligated to constantly take measures to ensure safe operation of the power supply systems. The so-called “system services” include maintenance of frequency stability, maintenance of voltage stability, restoration of supply after failures, and operational management. Battery systems are a fundamental element of the energy transition, in particular as a safeguard for system stability and system security, as they are able to contribute to the various system services.

– Maintenance of frequency stability ensures the balance between generation and consumption. Initially, this task is performed by the instantaneous reserve which is currently provided by the inertia of the rotating masses of the generators in large conventional power plants; this ensures that frequency variations are damped before control power is deployed.
– Maintenance of voltage ensures that the stability and the nominal system voltage do not exceed defined limit values. For this purpose, reactive power and short-circuit power are supplied as necessary.
– In the event of a large-scale power failure, the ability to restore supply is a crucial property of the electricity system. With the assistance of power plants with black start capability, the responsible system operator must be able to supply its system area with electricity in a controlled manner.
– Operational management mainly includes the monitoring of all generators and consumers connected to the electricity system as a whole; this task is performed by the TSOs, which detect any faults and initiate appropriate countermeasures. This also includes congestion management and feed-in management.

At present, only the supply of control power for frequency stability is put out to tender on a dedicated market in an open, transparent and non-discriminatory manner. All other system services, such as the provision of reactive power or maintenance of voltage stability are solely requested by the responsible TSO from conventional power plants. To ensure that such system services can likewise be offered by all players participating in the ever more distributed generating environment of the liberalised electricity market, it is necessary for new markets to be established on which the individual system services are put out to tender, similarly to the control energy market. This will enable facilities such as battery systems to be developed for the specific application case and operated profitably.

Primary control power
If the actual system frequency deviates from the nominal frequency of 50 Hz, primary control power, secondary control power and tertiary control power (minute reserve) are deployed one after the other in order to stabilise the system. Primary control power is activated fully automatically, triggered by the deviation of
the actual frequency from the nominal frequency of the system. The frequency deviation brings about a positive and a negative power output directly at the generating unit. In all synchronously interconnected control zones of the European integrated grid, primary control power is deployed in accordance with the respective shares of the different control zones in total electricity production. In order to balance the remaining frequency deviation in the grid and restore the nominal frequency, secondary control power cuts in and replaces primary control power supply after 5 minutes. Thus the primary control capacity is available for new frequency upsets. The higher-level controller of secondary control power supply in each control zone ensures that the planned exchange of electricity with other control zones is restored and the frequency deviation is compensated for. In this context, the frequency deviation is mathematically converted into an adjustment setpoint, which is then systematically and jointly met by the generator sets deployed for secondary control power supply in the integrated grid control system. In order to ensure that the secondary control range is kept available, secondary control power is replaced by minute reserve power if the frequency deviation persists. Minute reserve power is a scheduled product that is manually or automatically requested by the respective connecting TSO and is fully activated within 15 minutes from the moment the request was issued.

Battery systems are able to absorb energy from or feed energy into the grid within a few seconds. Owing to this, they are particularly well suited for providing primary control power. At present, a primary control power volume of ±1,250 MW is put out to tender in weekly auctions via an internet platform (see www.regelleistung.net) for the coupled markets of Germany, Austria, Switzerland, the Netherlands, Belgium and France. The minimum lot size is currently ±1 MW, and a technical availability of 100% must be ensured for the performance period from Monday 0:00 hrs to Sunday 23:59 hrs, if necessary by keeping available sufficient back-up capacity.

The provision of primary control reserve is remunerated by payment of a capacity price. After expiry of the deadlines for the submission of bids, the TSOs sort the bids received by capacity price offered and award contracts, starting with the bid with the lowest price, in ascending order until the demand for primary control power to be provided is covered. Unlike in the case of secondary control power and minute reserve power, the energy actually supplied is not paid for separately.

In order to ensure reliable operation of the supply system, plants that are not subject to a limitation of storage capacity are required to be able to supply the maximum primary control power for at least 15 minutes. While conventional plants are able to supply primary control power again when these 15 minutes have expired and a further system frequency deviation occurs, plants with limited storage capacity first need to adjust their charge condition before they can provide primary control power service again.

Simulations of the operation of battery systems during past major disturbances in the European interconnected grid show that the supply of primary control power for at least 30 minutes would have been necessary in order to contribute to system stability. Figures 1 and 2 show the frequency curves during real faults that occurred in September 2003 in Italy and in November 2006 in the overhead line crossing over the river Ems in Germany; the data were recorded at the Duisburg-Walsum power plant site. Both situations make clear that the provision of primary control power for a period of 15 minutes would not have been sufficient to compensate for the faults and continue providing primary control power until the normal condition of the system was restored.

![Fig. 1. System frequency during the incident in Italy.](image1)

![Fig. 2. System frequency during the incident at the Ems overhead line crossing.](image2)
period of just 15 minutes, then instabilities in supply and associated restrictions to system security are significantly more likely to occur in the event of major incidents.

From STEAG’s point of view and against the background of the cost depression expected for battery cells due to the ongoing expansion of battery storage capacity, it is even less understandable why a reduction of the service period to 15 minutes should bring an advantage at the expense of system security. As has been proven with the large-scale battery systems project it is already today economically viable – without drawing on subsidies – to build battery storage systems for primary control service even if the service period required is 30 minutes.

The large-scale Battery Systems project

STEAG has gained experience with battery systems for the provision of system services, such as primary control power supply, since 2009. With the LESSY (Lithium-Ion Electricity Storage System) project sponsored by the German Federal Ministry of Education and Research, one of the first lithium-ion storage units in Germany was approved for grid stabilisation service and has been successfully operated at the Völklingen-Fenne power plant site since 2013. Following extensive development work and acquisition of technical know-how, the battery system was prequalified for primary control service in 2014 and incorporated in the power plant pool for commercial operation.

After the LESSY research project, the experience gained was applied to large-scale battery systems and an economically viable concept for a battery system with 15 MW capacity was developed. Apart from the dialog with the transmission system operators about grid infrastructure and the necessary storage capacity, this also included an analysis of the primary control power market and the development of price scenarios for the future. Thereafter, a first business case was created and profitability calculations were performed.

After a positive assessment of the profitability of a large-scale battery system detailed specifications for a portfolio of six large-scale battery systems were compiled. Then, the technical equipment was put out to tender and the definitive investment criteria were defined. Once the six locations had been defined – Lünen, Herne and Duisburg-Walsum in the state of North Rhine-Westphalia, and Bexbach, Fenne and Weiher in the Saarland – the current regulatory framework was clarified with the competent authorities.

Upon completion of the decision-making and contract awarding process, implementation of the project started. Since battery systems and the creation of flexibility are instrumental in the implementation of the energy transition in Germany, the financing was deliberately structured without drawing on any subsidies, in order to demonstrate that even in the present market situation large-scale battery systems can be profitably operated in the primary control power market. Based on the planning and project management of STEAG Energy Services GmbH the installation of the large-scale battery systems has been pushed ahead at all six locations jointly with STEAG Technischer Service GmbH. Commercial operation has started at the end of 2016. Figure 4 shows a picture of the large-scale battery system at STEAG’s Lünen power plant site.

In all, large-scale battery systems with a total capacity of 90 MW have been installed at six sites, on a total area of more than 1,500 m². In order to satisfy the current requirements of the TSOs in Germany and provide the required primary control service for at least 30 minutes, each large-scale battery system has a total storage capacity of more than 20 MWh. The battery cells with highly efficient lithium-ion technology are arranged in containers in order to permit a change of location at a later time. This also helped to minimise the time required for manufacture and field erection. At each site, a total of 10 battery containers with a capacity of 1.5 MW each, five transformers and one control container have been installed.
STEAG is satisfied with the performance of the large-scale battery system since the start of commercial operation. For the future it is planned to investigate further applications of battery systems, in the provision of system services as well as cost optimisation and risk management of industrial locations. They are examining projects and cooperations in Germany and abroad.

Value creation
Virtual power plants will play a key role in the integration of distributed generating facilities and loads. Only when they are pooled in a virtual power plant they can be efficiently deployed in the electricity and control energy markets.

The interplay of renewable and conventional energies is considered to be an important step towards a successful energy transition. Therefore, the marketing in the electricity and control energy markets, balancing group management and provision of reserves for conventional power plants and distributed generating facilities have been combined in the optimisation network “STEAG OneOpt”. Thus, large-scale battery storage systems serve as a link between large conventional power plants, distributed facilities, renewables and the electricity market, which provides short-term flexibility and is thus an ideal complement for the company’s generating portfolio.

By pooling different technologies in the optimisation network it is possible to exploit many advantages of the individual technologies even better. For instance, for the required back-up for primary control power capacity, no redundant plants need to be built at the respective sites. If one battery system fails, the needed primary control power can be kept available or be supplied by another source prequalified for primary control service. In future, continuous adjustment of the charge condition of the large-scale battery systems will also be possible by drawing on the plants pooled in the optimisation network. Such use of energies will result in a substantial reduction of the operating costs of the battery systems.

Summary
With its large-scale battery systems project, STEAG is demonstrating that battery systems can already today make a substantial contribution to the security and stability of the electricity supply systems and that they can be profitably operated by participating in the primary control power markets.

As the share of energy from renewable sources continues to increase and, consequently, conventional plants are squeezed out of the market, the electricity supply system of the future will need an additional option to provide flexibility. Especially the high proportion of distributed infed on the medium voltage and low voltage levels calls for the provision of additional system services on these voltage levels.

Owing to their flexible positioning, large-scale battery systems are capable of providing system services on all system levels, and on both the regional and supra-regional scales. However, in order for the system adequacy under increasing grid restrictions it is necessary to establish new markets on which the individual ancillary services which have to be newly define are put out to tender. Only then it will be possible for all players in the market to participate in the provision of system services in a non-discriminatory manner and open to all types of technology. Thus, unbundling remains an important aspect for the future of energy supply as well on TSO as DSO level, in order to ensure that the competition for the best solution continues to drive the development of the energy sector.
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